Fs/ePHENIX: Update on Forward Spectrometer Design

Jin Huang (BNL)

Introduction

- Forward yoke modification is the foundation for fsPHENIX and ePHENIX, which require joint design at early stage of sPHENIX construction
- Including of forward yoke require significant design effort. But resource for financing, designing and building sPHENIX is limited. Forward arm will not appear automatically.
- Therefore the forward group want to be active in this effort
  - Physics cases,
  - **Update spectrometer design (This talk and next talk by Nils)**
  - Simulation

Concept for an EIC Detector
Hadron arm shared by fsPHENIX too

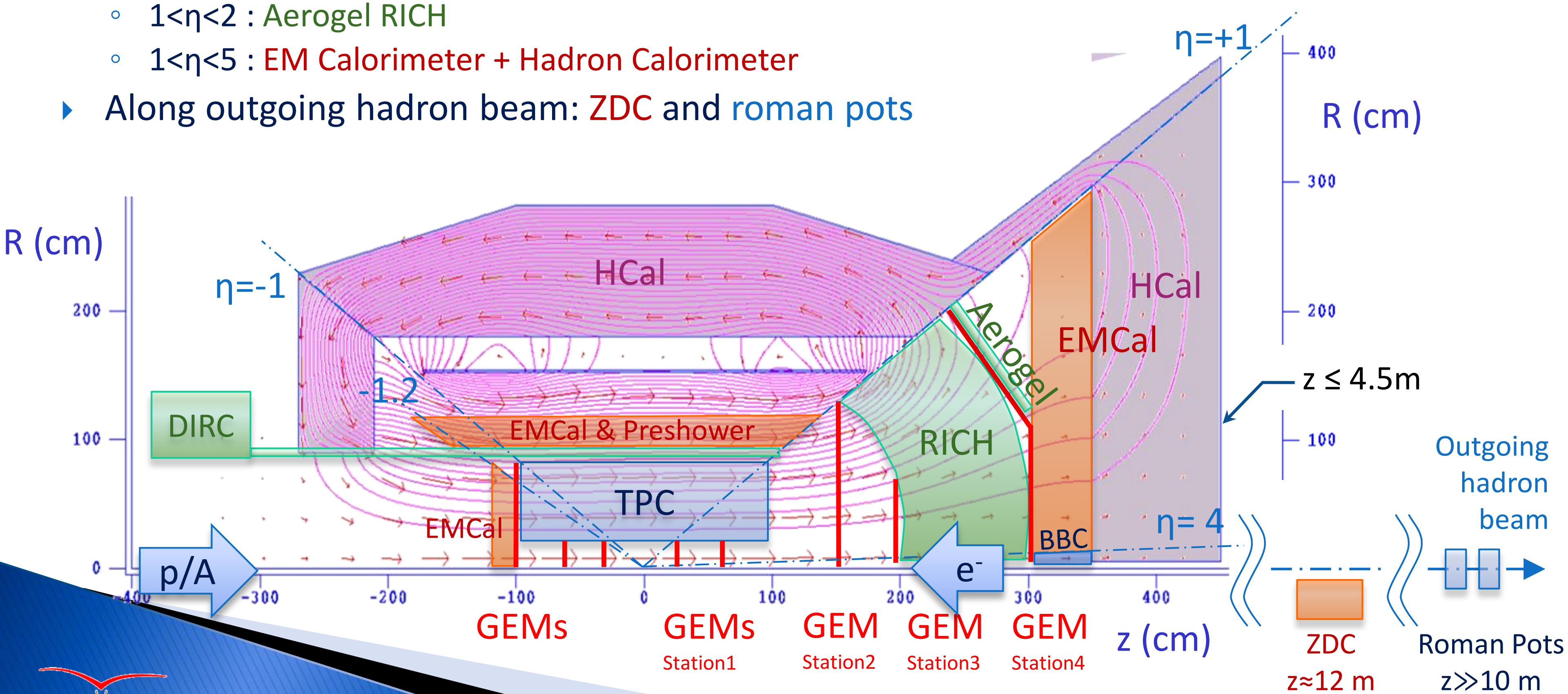
- $-1<\eta<+1$ (barrel) : sPHENIX + Compact-TPC + DIRC
- $-4<\eta<-1$ (e-going) :
  High resolution calorimeter + GEM trackers
- $+1<\eta<+4$ (h-going) :
  - $1<\eta<4$: GEM tracker + Gas RICH
  - $1<\eta<2$: Aerogel RICH
  - $1<\eta<5$: EM Calorimeter + Hadron Calorimeter
- Along outgoing hadron beam: ZDC and roman pots

Working title: "ePHENIX"

LOI: arXiv:1402.1209

Review: "good day-one detector"

"solid foundation for future upgrades"



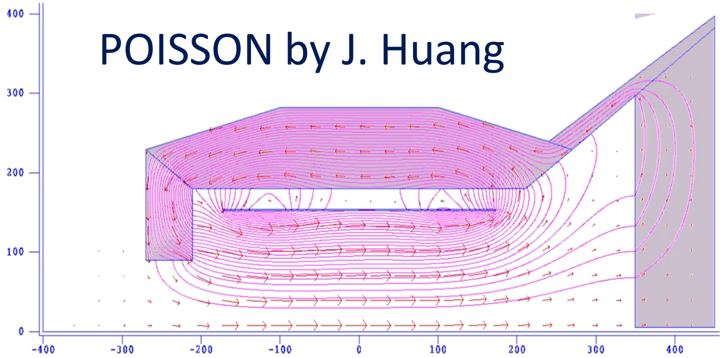
Considerations for the ePHENIX spectrometer field design

- Base on sPHENIX/BaBar magnet and yoke
- Open acceptance for both ePHENIX and fsPHENIX
- Stable magnetic design (force balance, internal stress, etc.)
- Practical limit
  - $|z|<4.5$m eRHIC detector region limit
  - Height limit of beam-rail of 4.5 m
  - No bending magnetic field on electron beam
- Detector requirements
  - Sufficient momentum resolution in forward region
  - Work with gas RICH: small bending field in RICH region
  - Work with TPC: homogeneous field in TPC region

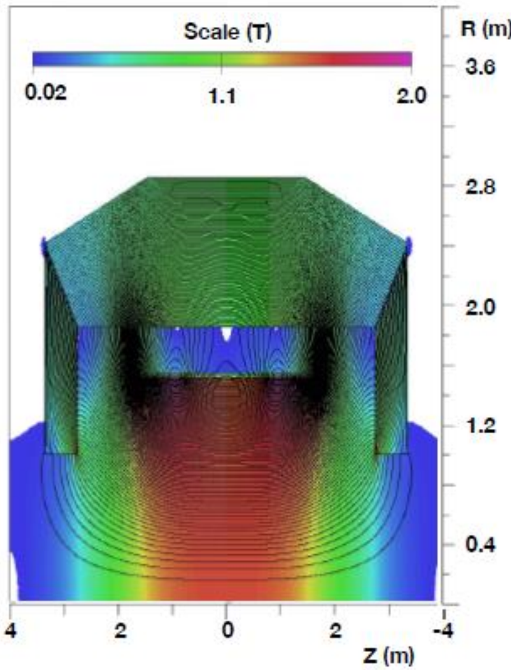
In last era of e/fsPHENIX field design

- 2D tools to get first tuning and evaluation by physicist
- New: field calculation (COMSOL) is now also available through StonyBrook Univ. (Nils Feege)

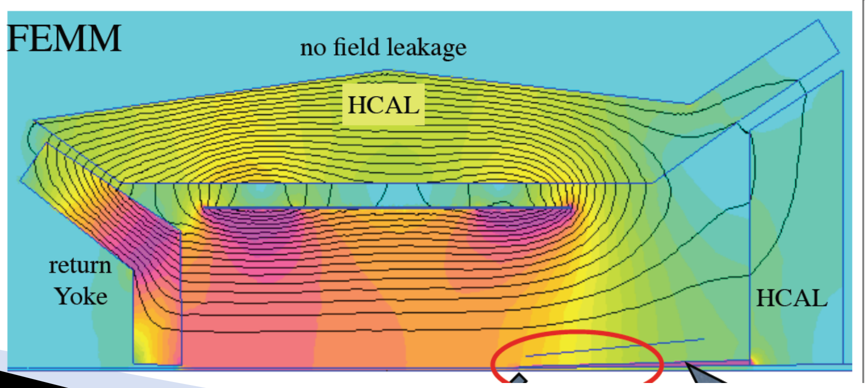
POISSON by J. Huang



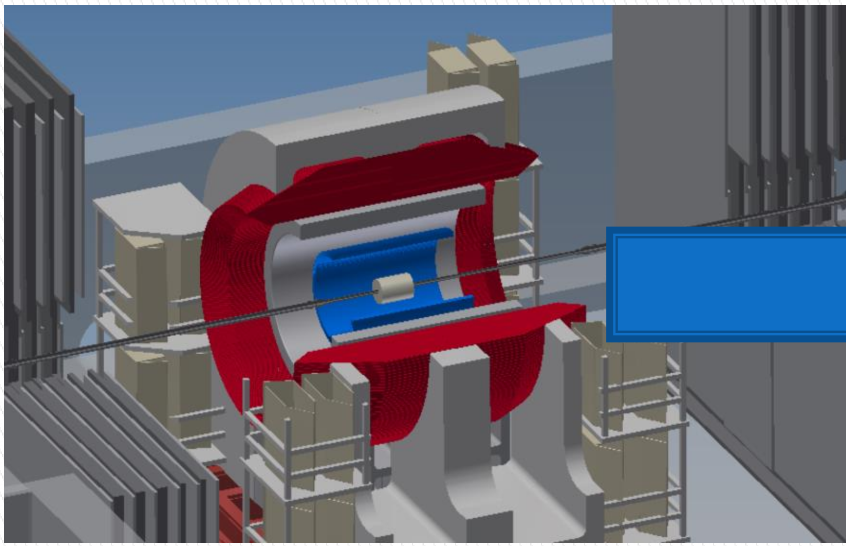
OPERA by A. Franz

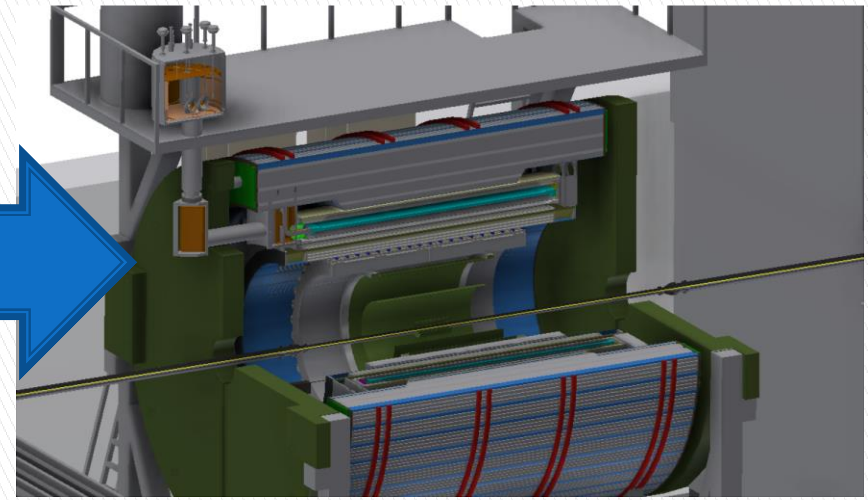


FEMM by C. L. da Silva



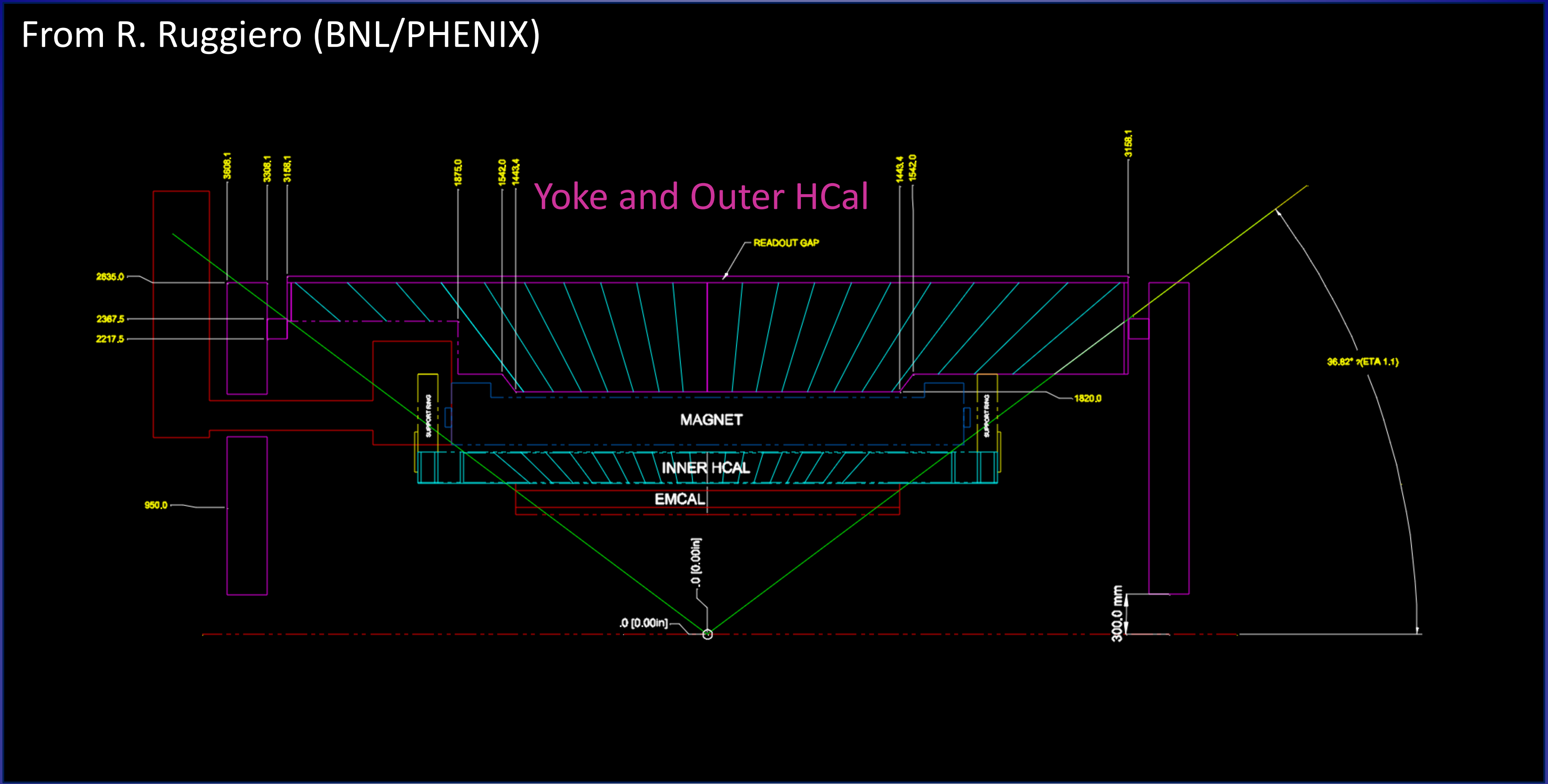
Since then, Update on sPHENIX design





sPHENIX concept, Sept 2013 MIE, foundation of fs/ePHENIX concepts

Updated sPHENIX concept Nov 2014 proposal

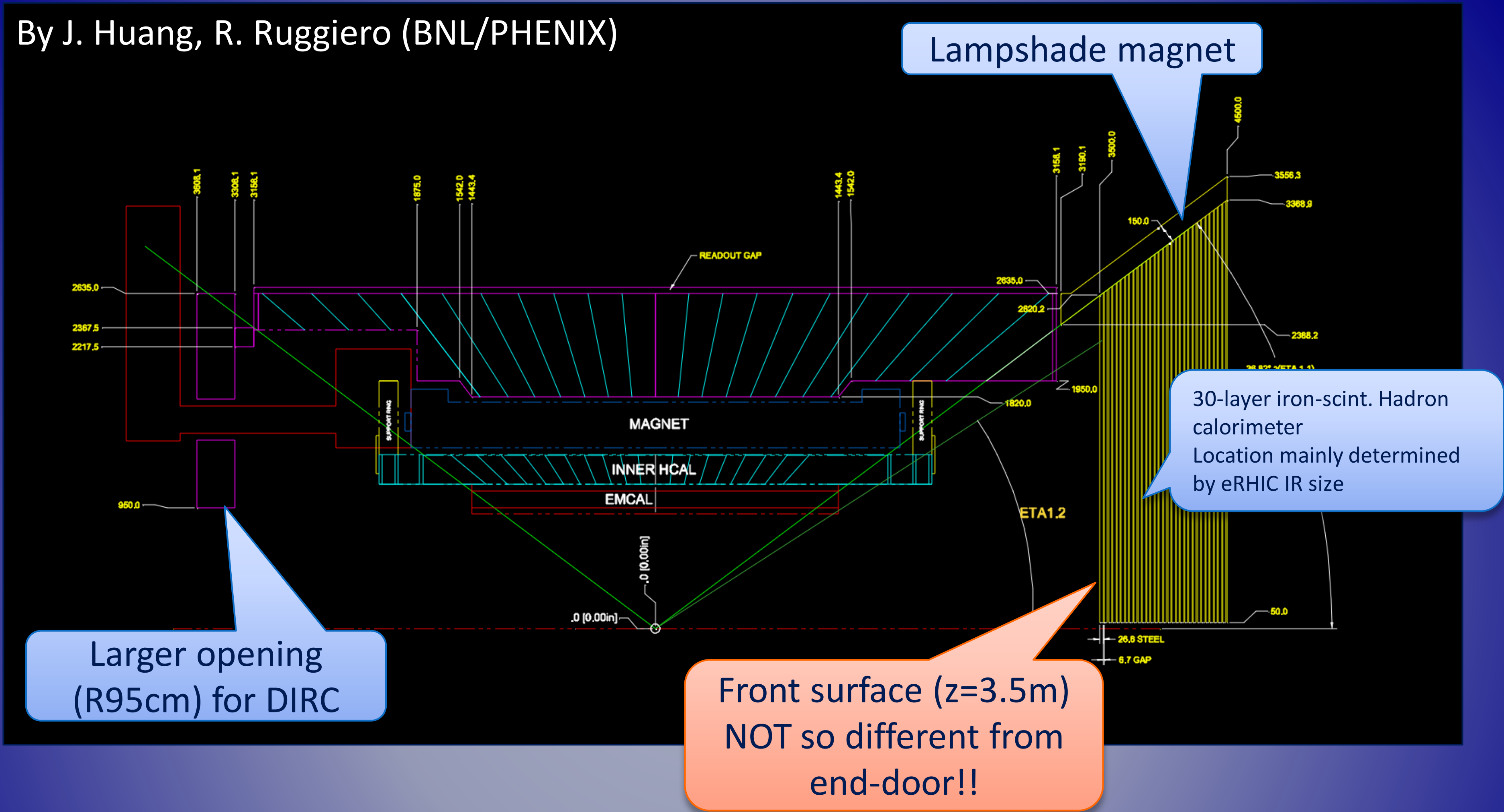


A recently updated sPHENIX mechanical drawing

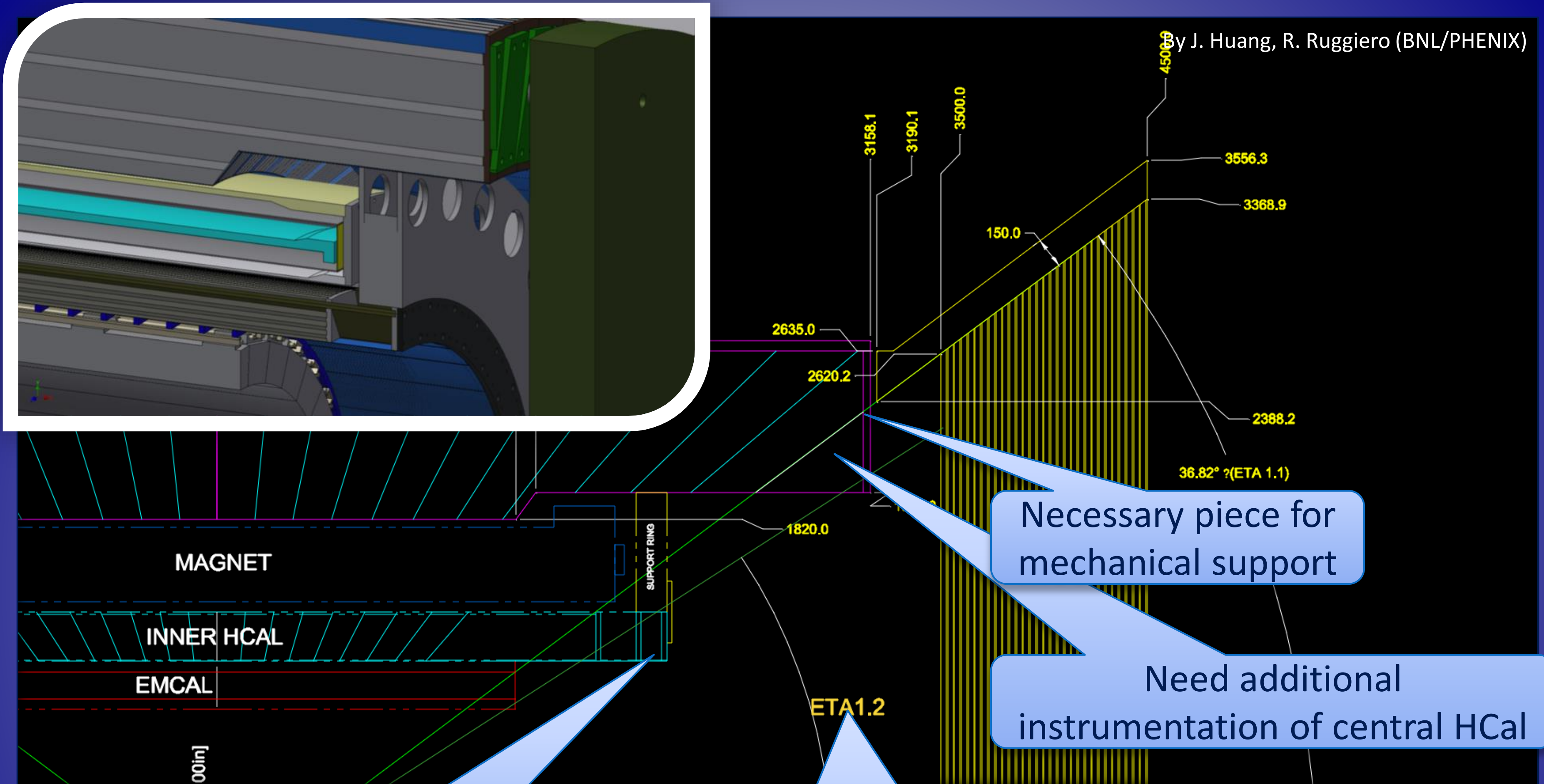
HCal geometry is significantly revised

End-door design

By J. Huang, R. Ruggiero (BNL/PHENIX)



An attempt to put in the forward spectrometer



Detailed design

Boundary between sPHENIX and fs/ePHENIX can be well covered by hadron calorimeters for jet measurements. Forward tracking/PID likely start from eta=1.2

Current status

- Auto-CAD drawing of the forward arm with updated sPHENIX spectrometer – COMPLETED (R. Ruggiero and J. Huang)
- Meet with CAD (W. Meng, K. Yip, Y. Makdisi) to discuss this design – COMPLETED (with A. Franz and J. Huang)
- Estimate the force balancing with updated yoke
  - Quick evaluation and tuning if needed: COMPLETED (N. Feege)
  - Professional evaluation: ON-GOING (W. Meng)
- What if asymmetric force is too much unbalanced?
  - Hopefully not since in new design, forward Hcal is not very far from end door (3.3 -> 3.5m)
  - May make the inner Hcal as field guild ring
- Can we use the south muon magnet as place holder for fsPHENIX? Not so easy though:
  - Piston – need to be removed
  - End wall – need to be shaped and moved to z=3.5m
  - Lampshade magnet – front need to be shaved to z = ~3m. Flux evaluation needed.

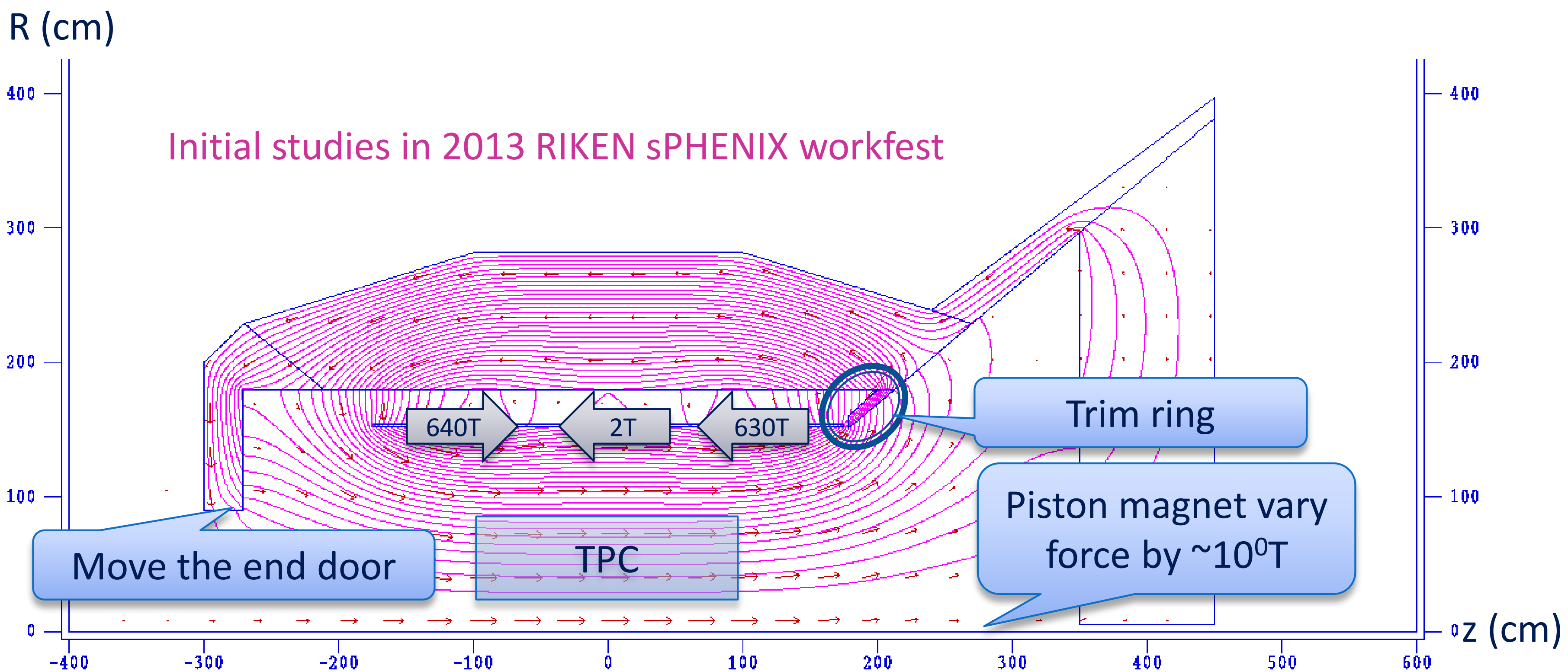
Summary – We are moving

BaBar magnet
Jan 16, 2015

Extra Materials

A static-force balanced magnet

- Preliminary force calculation done in 2D models to evaluate force and field uniformity
  - Default static force ~ 300T longitudinally
  - Possible to cancel such force with some field tuning
- Starting engineering study, need to understand realistic yoke, dynamic force

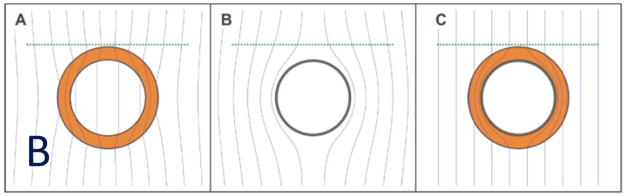


Field return design parameters

- Base on sPHENIX/BaBar magnet and yoke
- Open acceptance for both ePHENIX and fsPHENIX
- Practical limit
  - |z|<4.5m eRHIC detector region limit
  - Height limit of beam-rail of 4.5 m
  - No bending magnetic field on electron beam
- Detector requirements
  - Sufficient momentum resolution in forward region
  - Work with gas RICH: small bending field in RICH region
  - Work with TPC: homogeneous field in TPC region

Field return ideas investigated: We came a long way

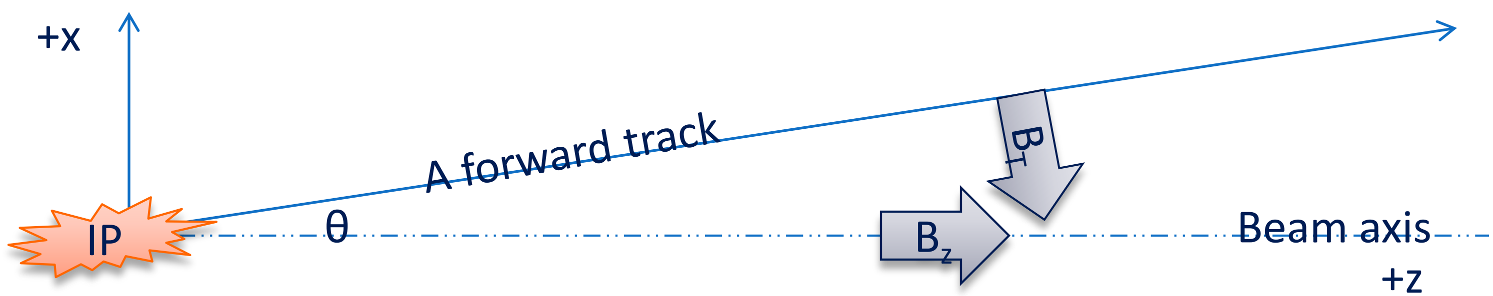
Design Family	Example
Piston	• Passive piston (C. L. da Silva) • Super conducting piston (Y. Goto)
Dipole	• Forward dipole (Y. Goto, A. Deshpande, et. al.) • Redirect magnetic flux of solenoid (T. Hemmick) • Use less-magnetic material for a azimuthal portion of central H-Cal (E. Kistenev)
Toroid	• Air core toroid (E. Kistenev) • Six fold toroid (J. Huang)
Other axial symmetric Field shaper	• Large field solenoidal extension (C. L. da Silva) • Pancake field pusher (T. Hemmick)



Beam line magnetic field shielding, based on superconducting pipe.
Test device planned (Stony Brook Group)

Tracking overview for forward directions

- Field transverse to the track → bending of the track → sagitta → measurement of (1/p)
- Besides brutal force increase of tracking resolution/field strength, geometry and field direction play an important role
- For a cylindrical symmetric field:



Transverse field is directly related to shape of central longitudinal field:

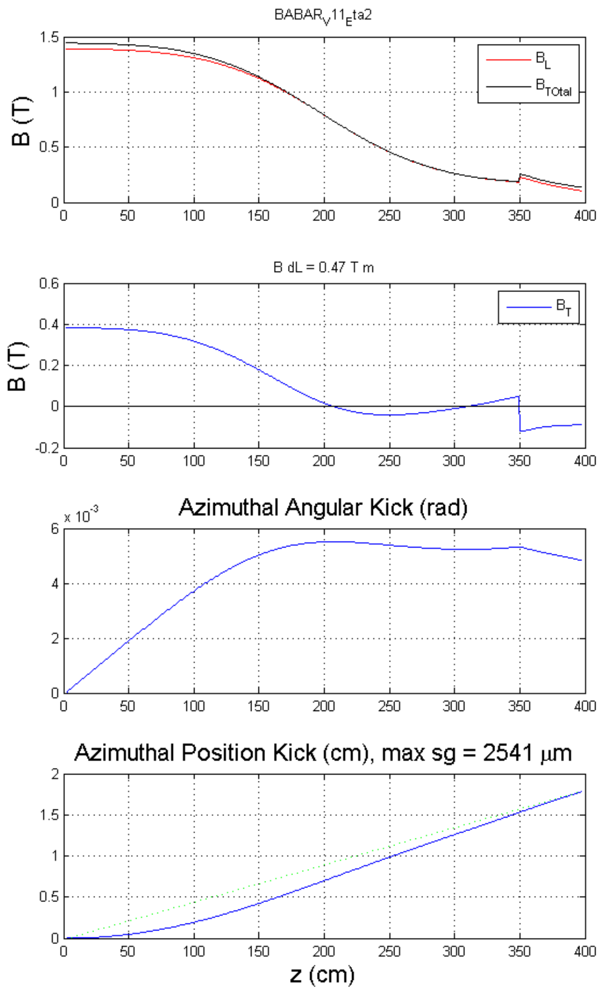
$$\boxed{B_T = B_z \tan\theta + \frac{\tan\theta}{2} z \frac{\partial B_z}{\partial z} + O\left(\theta^2\right)}$$

Geometry Term

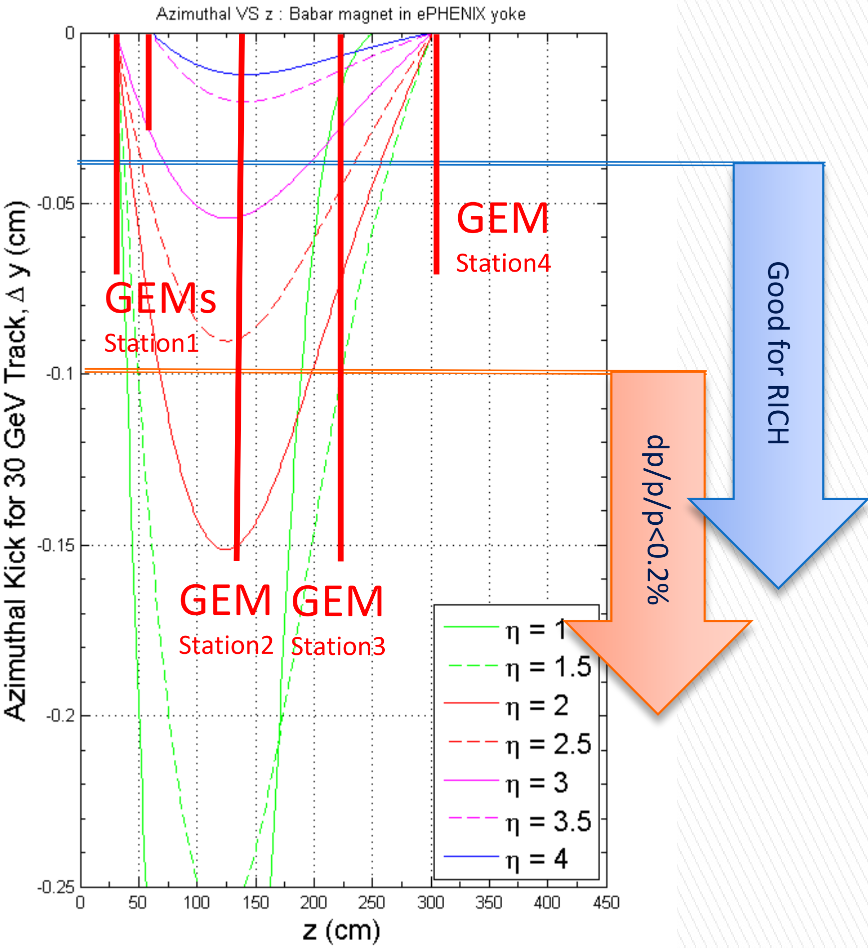
Flux Term

BaBar's graded current density help both

Tracking optimization with numerical field simulation



Using ϕ segmented GEM
with resolution of R Δϕ = 50μm



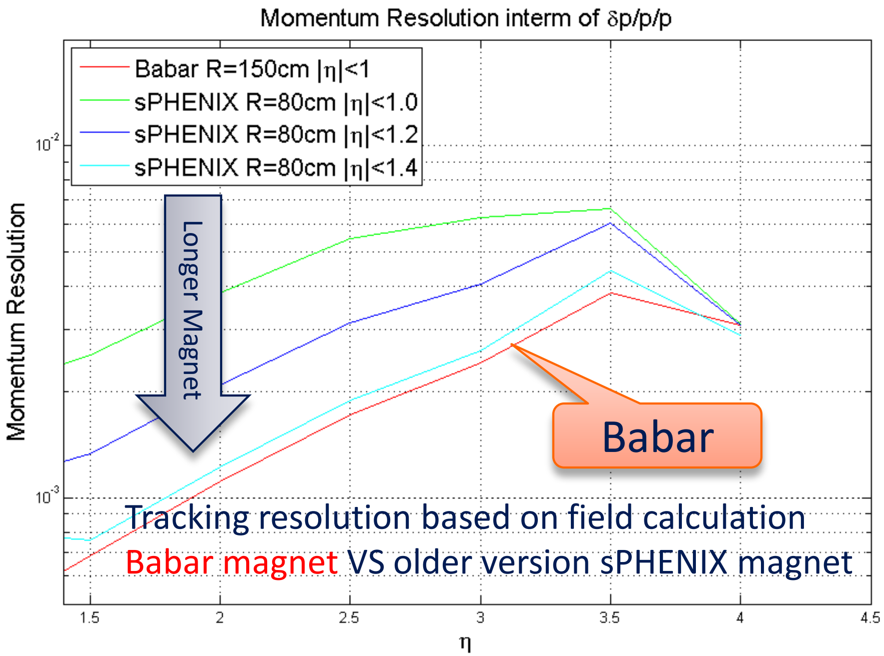
Magnetic bending
Track of η=2.0, p=30 GeV

Summary for sagitta
Track of p=30 GeV

BaBar + Field shaping

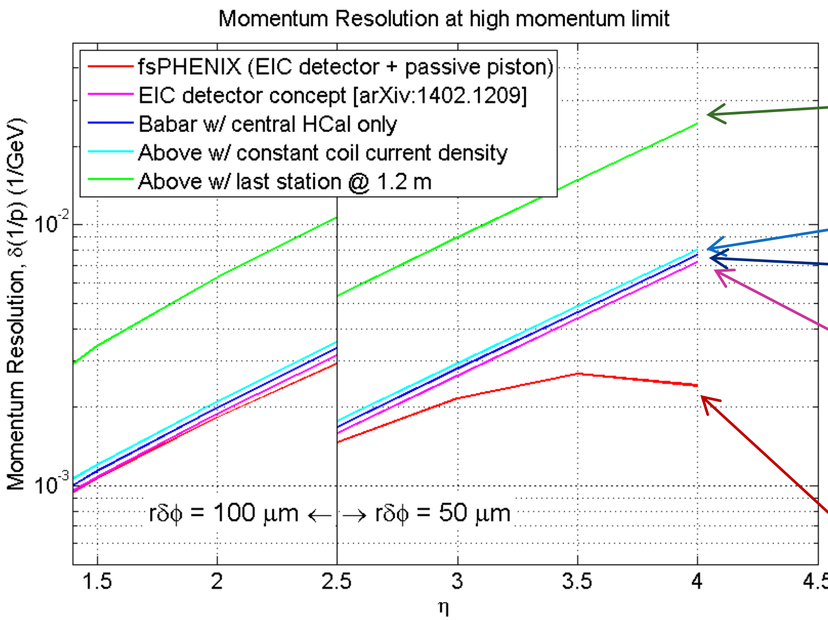
- BaBar superconducting magnet became available
  - Built by Ansaldo → SLAC ~1999
  - Nominal field: 1.5T
  - Radius : 140-173 cm
  - Length: 385 cm
- Field calculation and yoke tuning
  - Three field calculator cross checked: POISSION, FEM and OPERA
- Favor for forward spectrometer
  - Designed for homogeneous B-field in central tracking
  - Longer field volume for forward tracking
  - Higher current density at end of the magnet -> better forward bending
  - Work well with RICH with field-shaping yoke: Forward & central Hcal + Steel lampshade
- To be shipped soon

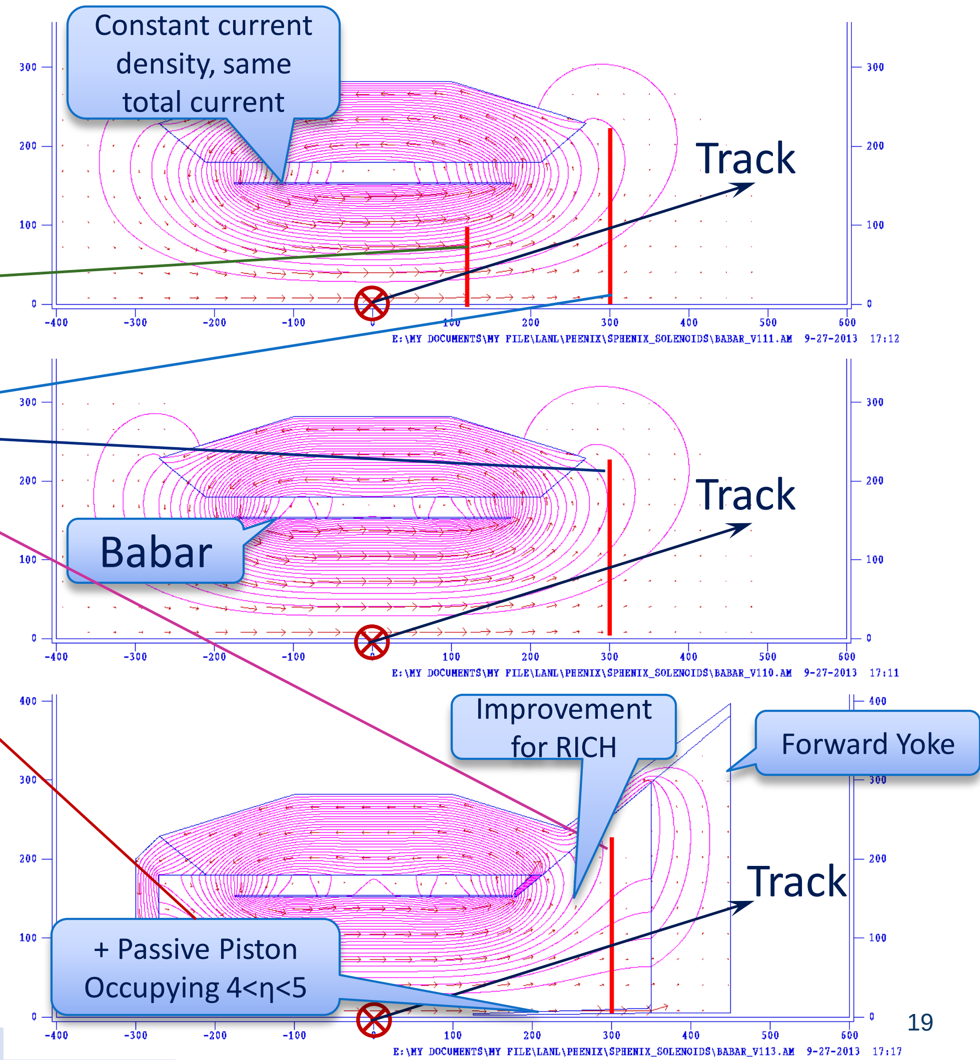
BaBar solenoid packed for shipping, May 17 2013



Considerations for yoke and tracking designs

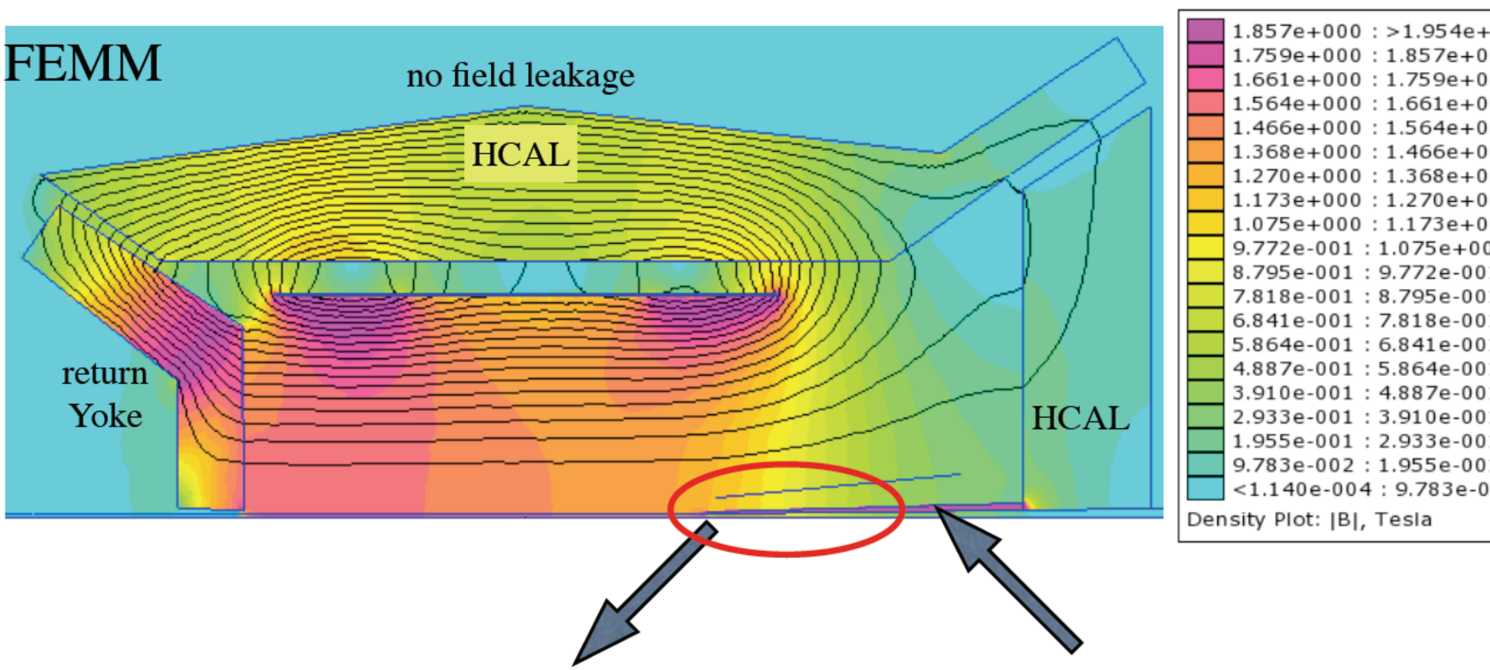
- Optimal tracking configurations
  - Measure sagitta with vertex – optimal sagitta plane (not drawn) – last tracking station
  - Yoke after tracking space and conform with a |z|<4.5m limit (eRHIC machine/detector t”ruce” line)
- Baseline forward tracking
  - Central + forward yoke (hadron calo.)
  - Last tracking station at z=3.0m
- Can be further enhanced for fsPHENIX DY

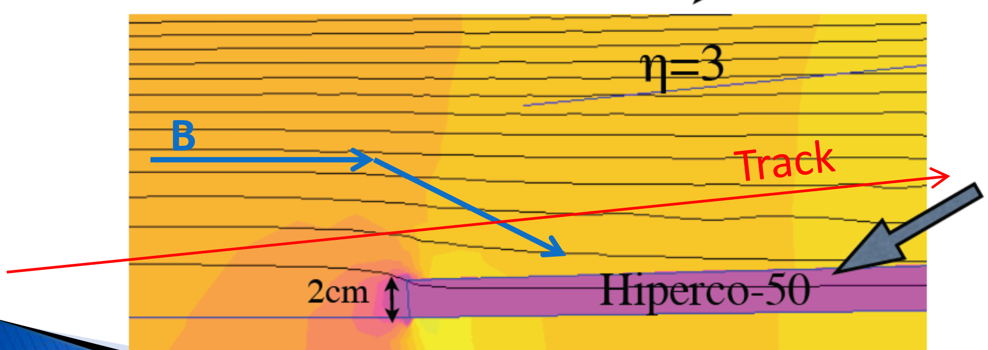




Very forward tracking for fsPHENIX: Passive piston field shaper

by C. L. da Silva





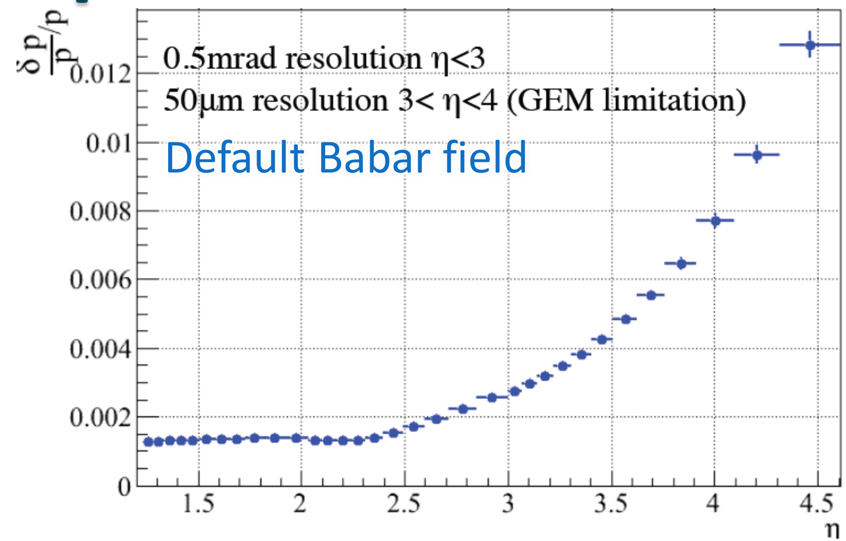
Passive Piston helping flux return at small angle

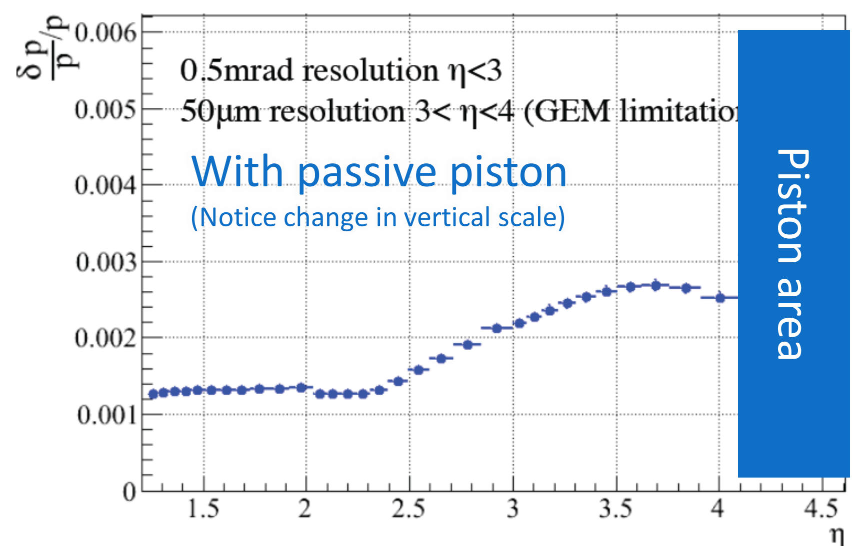
Hiperco-50: 49%Co+49%Fe alloy provide high field saturation (<2.25T)

Very forward tracking for fsPHENIX : Passive piston field shaper Performance

by C. L. da Silva

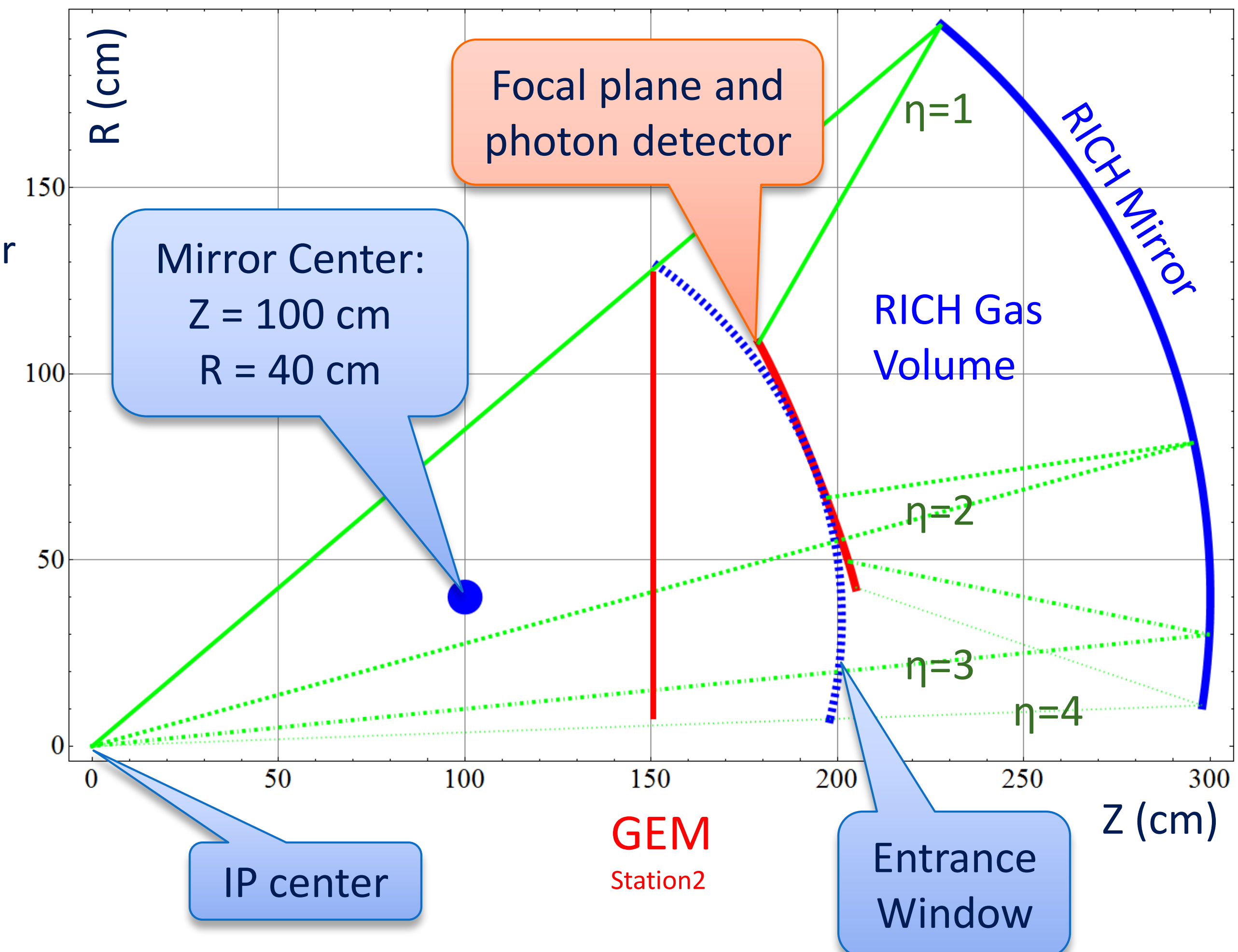
- Advantage :
  - Significantly improved very forward field where Babar field is least effective
  - Simple implementation
  - Minimal interaction with Babar field and beam
- Challenges that under study
  - Blocking Hcal acceptance of 4<η<5 for diffractive studies
  - Background shower from piston
  - Further improvement limited by total piston flux (may use silicon detector)
- Good ideas for improving momentum resolution is there. Not have to use for stage-I EIC, Not in LOI base design.





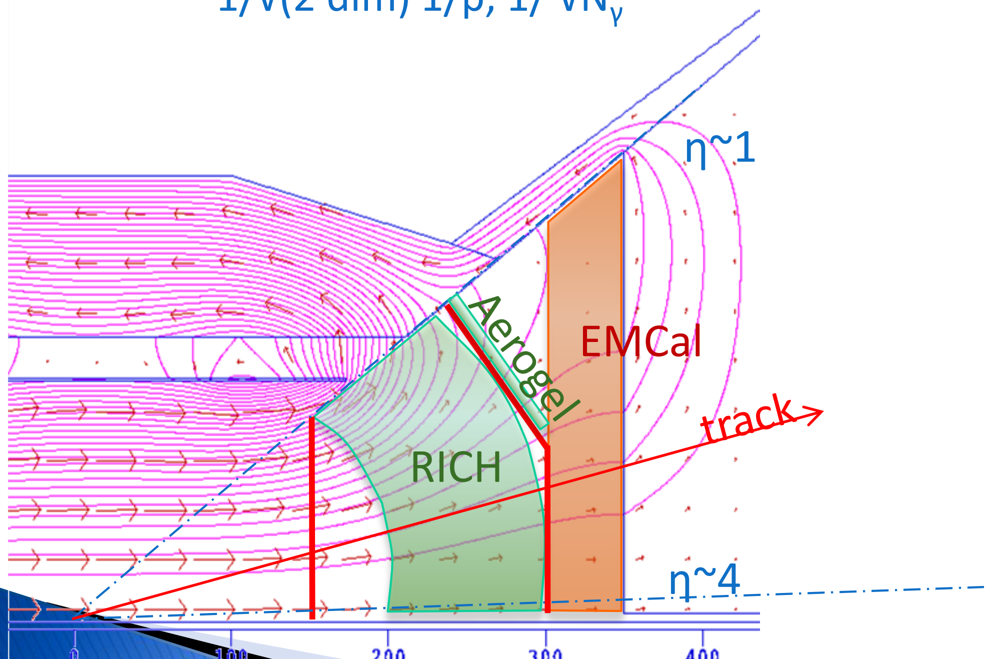
RICH with ePHENIX tracking and field: Proposed Design: R-Z projection

- "Beautiful" optics and assuming spherical mirrors
- 1 meter RICH gas volume along track
- Photon sensor is flat (easier for GEM construction)
- Small area for photon readout
- Avoid invading tracking space (Z > 1.5m, away from the optimal sagitta plane)
- Z < 3.0m from EMCal limit and allow a volume for aerogel at lower eta
- Defocusing due to extended vertex is small for most (Z-η). Defocusing <5% θMAX for worse case(Z-η) = (50 cm, 1.0)

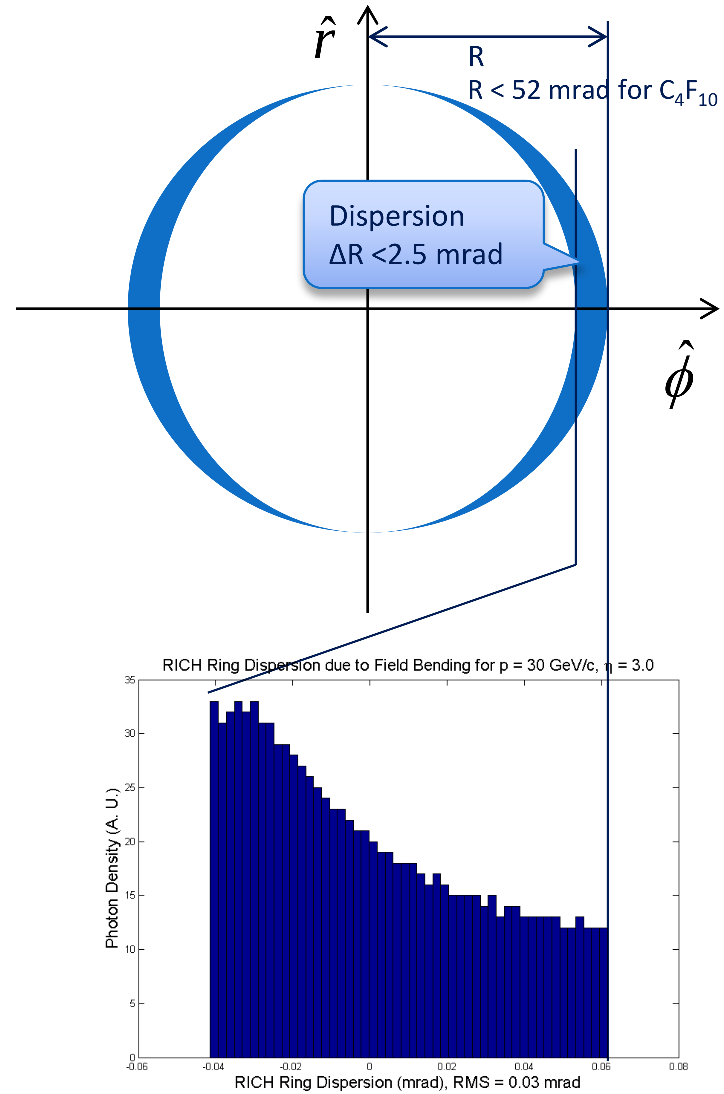


Estimating field distortion for RICH

- Field calculated numerically with field return
- Field lines mostly parallel to tracks in the RICH volume
- Field distortion of RICH ring only contribute to a minor uncertainty
  - Uncertainty on R suppressed by 1/√(2 dim) 1/p, 1/ $\sqrt{N_\gamma}$

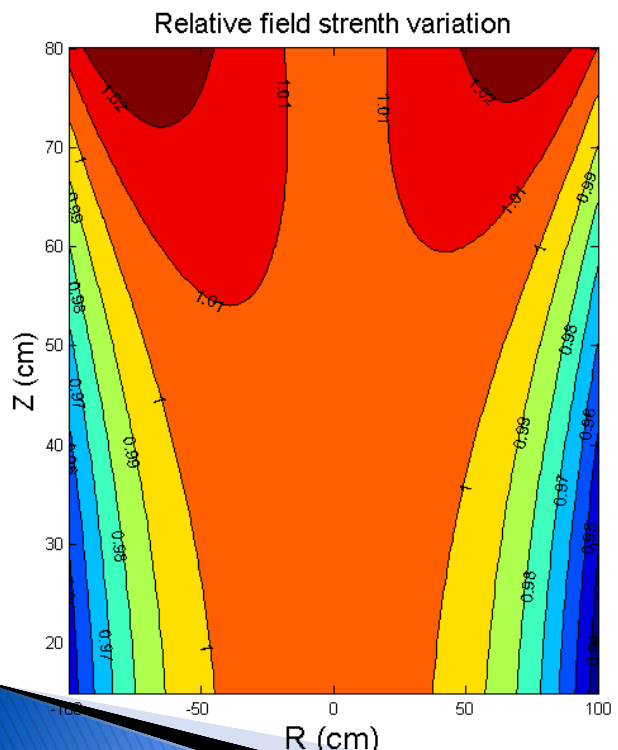


A RICH Ring:
Photon distribution due to tracking bending only

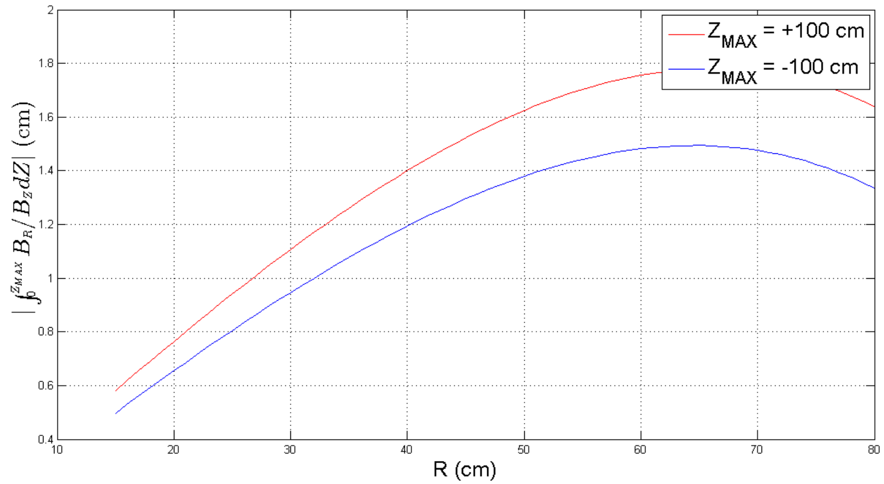


TPC region

- Reached quoted uniformity for Babar (±3% for central tracking volume)
- Looks promising for TPC work condition. Detailed study needed.



Field correction ~ few mm in Rϕ



Summary

- Current design satisfies the requirement in leading order
  - Base on sPHENIX/BaBar magnet and yoke
  - Open acceptance for both ePHENIX and fsPHENIX
  - Practical limit
    - |z|<4.5m eRHIC detector region limit
    - Height limit of beam-rail of 4.5 m
    - No bending magnetic field on electron beam
  - Detector requirements
    - Sufficient momentum resolution in forward region
    - Work with gas RICH: small bending field in RICH region
    - Work with TPC: homogeneous field in TPC region
- Need more work on
  - Justify the mechanical and dynamic stability
  - Simulation in details with detectors
  - Build it

Concept for an EIC Detector

- $-1<\eta<+1$ (barrel) : sPHENIX + Compact-TPC + DIRC
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